63-3-1

COPY NO.

TECHNICAL MEMORANDUM 1152

STATUS REPORT

RESEARCH FOR DETERMINATION OF BLAST EFFECTS ON RE-ENTRY VEHICLE STRUCTURE

LAWRENCE ROSENDORF
IRVING KINTISH

MARCH 1963

United States Army Munitions Command

PICATINNY ARSENAL
DOVER, NEW JERSEY

Technical Memorandum 1152

STATUS REPORT -

RESEARCH FOR DETERMINATION OF BLAST EFFECTS ON RE-ENTRY VEHICLE STRUCTURES

by

Lawrence Rosendorf

and

Irving Kintish

March 1963

Reviewed by: *JW Gregorits*
John W. Gregorits
Chief, Advanced Concepts Section

Approved by: *WR Benson*
W. R. Benson
Chief, Engineering Sciences Laboratory

Engineering Sciences Laboratory
Feltman Research Laboratories
Picatinny Arsenal
Dover, N. J.

Work on this project was supported by Army's NIKE ZEUS program and the Air Force Flight Dynamics Laboratory, Aeronautical Systems Division, Wright Patterson Air Force Base, Dayton, Ohio under Air Force MIPR 33 (657)-2-R&D-233.

ACKNOWLEDGEMENTS

Messrs. L. Adelson, R. Michael, H. Herman, G. Ward, H. Will III, F. E. Baker and N. Lockhart for all instrumentation in the tests. Mr. Murray Weinstein, Special Assistant to the Engineering Sciences Laboratory, and Mr. Digindra Sen, Chief of the Advanced Systems Unit, for their part in direction of the program and review of this report.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

This report outlines the experimental work performed by Picatinny Arsenal during the period 1 July 1962 to 1 January 1963 to derive by model testing, analytical and experimental techniques for the determination of blast loading and target response of ballistic missile re-entry structures. This information is considered a prerequisite in determining the kill and vulnerability of such targets to nuclear attack. Simple shell structures, of varying geometric parameters, have been instrumented with pressure transducers and strain gages and subjected to air blast from varying H. E. charge weights. A preliminary analytical approach to predict the incipient buckling pressure of the targets (cylindrical portion only), has been developed. This approach is based on a "dynamic load factor" which enables one to compute the dynamic buckling pressure from the static formulations. Plans are discussed for multi-ton H. E. tests.

Introduction

This report is submitted to the Flight Dynamics Laboratory, Aeronautical Systems Division, Wright Patterson Air Force Base for work conducted under Air Force MIPR 33 (657) -2-R&D-233. Past work has been jointly funded by ASD and Picatinny Arsenal, and is now being continued as part of the DASA WEB blast program; sub-task 01.019, Blast Effects on Re-entry Vehicles. The experimental work on this phase of the 01.019 program is the responsibility of the Ballistic Research Laboratories and Picatinny Arsenal.

This report presents the results of Picatinny Arsenal's efforts on the Blast Effects on Re-entry Vehicles program during the period July 1962 to January 1963. The results of the initial work are reported in Picatinny Arsenal Technical Memorandum Number 114-62 (Reference 1).

Objectives

The basic objective of this program is to derive experimental and analytical techniques for determination of blast loading and target response of ballistic missile re-entry vehicles in order to determine the conditions leading to kill of these targets. The course of action currently planned by BRL-PA is primarily that of a systematic progressive development of information on the response of missile bodies, beginning with deformation by impulsive loading on stationary targets and continuing to consider all possible factors in the actual dynamic re-entry situation.

The objective of the initial experimental phase of the PA effort is limited to determination of pressure loading and structural response of simple RV geometrical shapes (viz. cylinders, cones, and hemispheres) for extrapolation to the impulsive loading effects characteristic of duration times of nuclear detonations. The preliminary work is limited to the use of stationary targets in order to obtain the basic data required before going on to the dynamic situation of actual re-entry vehicles. The approach is to measure the surface pressure loads and structural deformation resulting from chemical HE bursts over a wide range of HE charge weight. Data points will then be obtained for as wide a spread of impulse duration times as possible. Attempts would then follow to extrapolate the data and develop analytical expressions for target response that will be valid in the higher impulse duration region, characteristic of nuclear detonations. It will then be desirable to test these predictions by subjecting models to full scale nuclear tests and adjust the theory as required.

Current Test Program

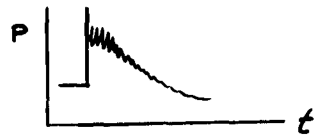
In the current experimental portion of the blast program at Picatinny Arsenal, models are mounted on test stands and subjected to air blast loadings from chemical high explosives. The tests at Picatinny are limited to 50 lbs. of high explosives. The models being tested are a combination of truncated cone and circular cylinder with hemispherical end caps, to include the basic geometrical shapes of interest for re-entry vehicles. The present models have two skin thicknesses, 1/8 inch and 1/16 inch. The cylindrical portions of each model are 7-1/2 inches in diameter and 7-1/2 inches long, and the conical portions have a R_2 = 7-1/2 inches, R_1 = 5 inches, and L = 7-1/2 inches. The total length of each model is 20 inches. The models are fabricated of aluminum and are reinforced by 3/8 inch aluminum bulkheads separating the cylindrical and conical sections from the end caps. The model having a 1/16 inch wall thickness is noted as target 1 and the model with a 1/8 inch wall thickness is noted as target 2. (See Figs. 1 thru 5). Additional photos of interest, Figs. 6 and 7 are also included.

Tech Memo 114-62 (Reference 1) describes Phase I of the blast program. Entailed are the evaluation of test stands and instrumentation check-out. It was decided that the test stands were to be made as rigid and immovable as was practically possible. Dr. R. Cooper of Aerospace Corp. suggested the need for accelerometers to be mounted on the bulkheads of the models so as to monitor the movement of the model in its supported condition. Time of arrival gages were placed alongside the models so as to determine the free air over pressure.

In phase II of the program the models were instrumented more fully. Atlantic Research Corp., pressure transducers were flush mounted on the skin of the model at 0 degrees and 45 degrees on both the cone and cylinder portions. Baldwin-Lima-Hamilton-SR-4 strain gages were mounted at 0 degrees and 90 degrees on both the cone and cylinder. The models were placed 15 feet from 10 lbs. of composition C-4 explosive. Two 4-beam oscilloscopes coupled with 35 mm framing cameras were used to record the data.

Twelve tests were performed and the data was reduced. The pressure-time records indicated a spike followed by what is believed to be gage-resonance. A sample pressure-time record is sketched below for a 0° Position. Figures 12 and 13 are the actual pressure-time records for the cylindrical and conical portions of

the target for test SP-3 (See Table 1).



This is typical of the records obtained at the face-on position of the cylinder and cone. The peak pressure (spike) has been explained as the Rankine-Hugoniot Peak reflected pressure.
This is computed from the relation,

$$\frac{P_r - P_o}{P_s - P_o} = 2 + \frac{6P_s}{P_s + 7P_o}\text{,}$$

where; P_o=ambient pressure

$P_s - P_o$ = Free Air over pressure

$P_r - P_o$ = Peak reflected pressure

For $P_s - P_o$ =24.04 psig at 15 ft. from 10 lbs. C-4 explosive and P_o=14.7 psia, $P_r - P_o$ = 88.8 psig.

The average of 10 reflected pressure peak spikes is 88.3 psig at the zero degree (face-on) position on the cylinders, which is in excellent agreement with the R-H. predicted value. The average of nine reflected pressure peak readings taken from the cone in a face-on condition was 117 psig.

Since the peak spike pressure occurs almost instantaneously, the positive impulse resulting from it does not contribute significantly to the total impulse that the target sees. Glasstone (Ref. 2) suggests that for large cylindrical structures, the duration of the reflected pressure portion of the pulse can be approximated by $t_s = \frac{3\text{x Radius}}{\text{Shock velocity}}$. For our specific case this would lead to $\frac{3R}{U}$ = .535 msec. In the Picatinny Arsenal tests, the total positive phase duration is approximately 2 msec and as mentioned before, the reflected pressure portion occurs almost instantaneously. Thus, data obtained in this respect does not agree with Glasstone's formulation. As future tests are performed on various geometric targets, this formulation will again be checked.

It should be further pointed out that the data was reduced from the film records by averaging the resonant peaks and omitting the spike for reasons mentioned previously. The data is presented in Table 1.

TABLE 1

Average Peak Reflected Pressure (psig) Omitting Rankine-Hugoniot Spike

Shot #	0° Cyl.	45° Cyl.	0° Cone	45° Cone
18	63	54	50	48
19	64	--	43	42
20	73	--	91	47
21	74	50	73	29
22	54	46	83	29
23	57	47	96	29
24	50	30	77	--
28	62	47	90	23
sp3	59	64	69	38
4	54	74	85	53
5	68	60	89	43
6	45	77	53	52
AVG.	60.3	46.7	75	35

All of the data was reduced by the same person and in the same manner so as to eliminate, as much as possible, differences in interpretation of the film records. However, due to the "resonance" that takes place the interpretation is still somewhat vague.

Despite these difficulties two points seem to be of general interest. The first and seemingly obvious point is that in most cases the pressure was higher at zero degrees than at 45 degrees on the cone and cylinder, though individual variations existed. The second point that was observed is that the average 0° pressures on the cone were higher than the corresponding pressures on the cylinder while the average 45° pressures on the cone were lower. Here again individual variations existed and the data is not yet felt to be adequately reproducible. Further study is needed in this area to determine the diffractive pattern of the shock wave over the cone. It is felt that the use of a shock tube could prove extremely valuable.

Several possible sources of error have existed in our experiments. The most probable and significant of these is the fact that the composition C-4 explosive was hand molded at the test site. Variations in symmetry and density of explosive undoubtedly existed and could account for some part of the deviation noted. It is suspected that "end effects" existed and created a non-hemispherical shock wave.

In the initial experiments a surveyor's transit was used to align the explosive and target. As subsequent experiments were carried out, the craters formed by the explosive had to be refilled. The elevation of the explosive charge used in these subsequent tests was therefore subject to slight variations as the "refilled-crater" was not perfectly leveled. Visual alignment of explosive and target was employed, as a transit was not available for these later experiments.

Another possible error source lies with the initiation techniques. A No. 8 blasting cap was centrally located on the flat side of the hemispherical charge. On several instances however the blasting cap was placed on the surface of the charge. The depth to which the blasting cap was inserted was likewise not closely controlled.

All of the planned future experiments are designed to benefit from the shortcomings and experience gained in the earlier experiments. Cast composition B hemispheres with machined cavities to accommodate the blasting cap have been prepared. It is expected that a surveyors transit will be available so as to insure proper alignment. Several new pressure gages are under consideration for incorporation in later tests. The resonant frequency of these gages are believed to be high enough so as to eliminate the "ringing" noted in the present gage records. As human error is eliminated and repeatibility is obtained, experimental tolerance bands will be computed based on the logarithmic derivative method. Subsequent tests should indicate whether this "gage ringing" is a function of the gage or the system. The natural frequencies of the target will be calculated (Ref. 3) and compared with the "ringing" frequency noted in the reflected pressure records. Dr. Emmet Wittmer of Massachusetts Institute of Technology earlier had suggested that a diameter to thickness ratio of 60 to one for our target is too low to excite any but the first vibrational mode. This will be investigated further.

Also under consideration for future tests is the use of a 7 channel tape recorder. This would enable us to instrument the models more fully. Based on our discussions with the personnel of Suffield Experimental Station, methods are being studied by our instrumentation group to improve their field calibration technique.

The present experiments at Picatinny involve the use of one target model mounted on a stand 15 feet from the explosive charge. It is felt that this represents a high inertia type system. One of the experiments planned for the future is to freely suspend an instrumented target and subject it to the same level of blast as the rigidly mounted targets. The records will then be compared

so as to assess the major differences and to explain whether or not a ground coupled shock exists and is distorting the records. The majority of the experiments currently being conducted at the Picatinny Arsenal test range are with Target No. 2 at free air overpressure levels of 25 psi and 75 psi. Strain data at the 75 psi overpressure level has not been recorded as yet but this will be incorporated into the next series of experiments. It is interesting to note that the duration of the strain information appears in good agreement with the duration of reflected pressure measurements. When plotted on a common axis, the strain time histories (See Fig 8-11) all follow similar shapes. The figures are not true representations of the actual strain time histories. They were drawn by simply connecting maximum and minimum points from the original traces. They are placed here merely as an indication of the reproducibility of the strain data as to general shape. The amplitudes vary somewhat due to the variations in reflected pressure, resulting from the experimental errors discussed previously. After the first few cycles the strain traces become rather spurious. The maximum strain recorded for an overpressure of 25 psig was 183 micro inches per inch. For an aluminum shell having a modulus of elasticity of 10^7 psi, the 25 psig overpressure leads to a stress of 1830 psi. Based on the experimental data of W. Schuman of BRL, target No. 2 should fail at an overpressure of 167 psi from 10 pounds of explosive. As future experiments are carried out it is expected that the stress at which a target buckles will be determined. For hard targets, buckling may not be a principal criteria for damage and the determination of the experimental stress level at which yielding occurs could prove valuable. Figure 12 is an actual oscilloscope record of the strain time history for test SP-3.

Planned Tests at Off-Arsenal Site

It is presently planned that several large scale tests will be conducted at a proving ground during the spring or summer of 1963. Inquiries were sent to White Sands Proving Grounds, White Sands, New Mexico; Yuma Test Station, Yuma, Arizona, and Naval Ordnance Test Station, China Lake, California. The replies were considered, with respect to cost and facilities available, and it was determined that Yuma or White Sands would be most suitable for a planned test purpose.

At White Sands there is available a 17 channel, high frequency tape recorder set up in a trailer, blast pressure gages and a 16 channel cathode ray tube high frequency recording unit. In the past, White Sands has successfully detonated multi-ton charges of H. E. They will build the hemispherical charge, supply photo coverage, supply trailers and vans for our equipment, and aid in data reduction.

Yuma Test Station has on hand 8 channels of oscilloscope equipment and 13 channels of high frequency tape recorders. They could also supply another 4 channels of high frequency recording equipment if Picatinny Arsenal was to provide the cathode followers for the gages. At Yuma, due to their summer environmental test programs, the possibility of delays is present.

A final decision as to which facility will be used will be made shortly in coordination with BRL.

The tests to take place at a proving ground site are presently planned to use one-ton and five-tons of TNT for two separate experiments. Picatinny Arsenal will supply four 4-beam oscilloscopes to supplement the instrumentation at the proving ground facility. A total of forty channels of information would then be recorded during each test. Four models of various geometric parameters will be instrumented with 10 channels of information on each model. Four channels of blast pressure (face on and 45°), four channels of strain (face on and 90°), and two channels of free air information will be obtained from each model. The use of a strain gage having a transverse sensitivity coefficient such that stress may be read directly, is presently being investigated (Reference 13). This gage not only reads stress directly but also permits the use of only one channel of information to measure strain in two directions. If more channels of high frequency information become available, additional models will be instrumented.

Also proposed for the large scale H. E. tests would be the emplacement of approximately 20 uninstrumented models on test stands subjected to a variety of pressure levels. At present it has been planned to have 4 different models available for tests. These will be cone-cylinder combinations with hemispherical end caps. The cylindrical portions of the models would have the following dimensions.

Target 1 - 7-1/2" dia. cylinder x 20" long x 1/16" wall thickness

Target 2 - 7-1/2" dia. cylinder x 20" long x 1/8" wall thickness

Target 3 - 10" dia. cylinder x 20" long x 1/ 16" wall thickness

Target 4 - 10" dia. cylinder x 20" long x 1/8" wall thickness

(See Figures 2, 3, and 4 for typical target configurations). The models are fabricated of 6061 T6 aluminum. These have diameter to thickness ratios of 120, 60, 160, and 80, respectively. These models will be visually inspected and photographed to ascertain any damage. The models will encompass an overpressure region from approximately

3 psi to a region approximately 3 times greater than that predicted for incipient buckling by Schumann's work pertaining to our specific models (See table 3 in later section of this report). Attempts would then follow to determine "kill" criteria based on the damage levels of the uninstrumented models. Free field pressure gages will be placed at the uninstrumented model locations if additional high frequency recording equipment is available. Otherwise, durations, overpressures and impulses will have to be scaled from TNT and pentolite experimental data.

The four instrumented targets will be placed in overpressure regions somewhat less than the predicted incipient buckling pressures of Table 3. It is necessary to keep the instrumented targets in the elastic response range, and at a pressure level somewhat below the predicted incipient buckling pressures for the targets, as the strain gages are limited not by the modulus of elasticity of the target but by the modulus of elasticity of the bonding material which fixes the strain gage to the target. The response of the models at these overpressure levels will be recorded through the strain gages and will then the correlated with the tests at Picatinny Arsenal at similar overpressure levels but at lower durations and consequently at lower positive impulses.

Table 2 below indicates the scaled durations and impulses of interest for the overpressures noted, (Reference 4, 5, 6).

TABLE 2

Charge weight (w/ Reflection Factor = 1.8) # TNT	Scaled Range	Over Pressure	Duration msec	Side on Positive Impulse (lb msec/in^2)
20.7 lbs.*	5.44	25 psig	3.0	30.3
103.5 lbs.*	3.20	75 psig	2.35	65.[illegible]
3,600 lbs.	5.44	25 psig	17	170
3,600 lbs.	3.20	75 psig	7.7	216
18,000 lbs.	5.44	25 psig	29	290
18,000 lbs.	3.20	75 psig	13.15	368

* These tests have been performed at Picatinny Arsenal and will be repeated with the intent of minimizing experimental error.

Table 3 indicates the expected dynamic buckling pressures for the targets and weight of explosive noted and tabulates these alongside the computed static buckling pressures.

TABLE 3

Predicted Buckling Pressures of Cylindrical Portion of Targets

Target	Dynamic Buckling Pressure *a				Static Buckling Pressure	Reflected Pressure Factor
	2000 lbs. TNT		10,000 lbs. TNT			
	*b	*c	*b	*c		
1	37 psig	32.1 psig	34 psig	31.0 psig	150 psig	2.5
2	94	110	87	100	850 "	4.5
3	24.5	13.2	24	13	40 "	2.0
4	65.5	49.6	61.5	46	216 "	2.5

*a - In terms of free-air overpressure for the explosive noted.

*b - These pressure levels are predictions based on the experimental data of W. Schuman of Ballistic Research Labs. (Reference 11)

*c - These pressure levels are calculated based on Picatinny Arsenal Report No. 61-EA-28 by Carl Larson (Reference 7). (See Appendix)

Two techniques have been employed to predict the incipient buckling pressures. Good agreement is observed for both techniques for targets 1, 2, and 4. Target 3 however does not enjoy this proximity. Since Schuman's work is based on experiment it might be reasonable to assume that the theory used to predict the incipient buckling pressures based on triangular pulse loading is in need of some correction in the low pressure region. The determination of the incipient buckling pressure based on the triangular pulse loading is outlined in Appendix 1. Briefly stated, the approach is to compute "dynamic load factors" for the targets based on a triangular type of impulse loading and assume that the deflection of the fundamental mode is approximately equal to the deflection of an equivalent static load. The target is analyzed as a simple system with a single degree of freedom. This is true provided that the duration of impact is sufficiently long (a tenth or more) of the fundamental natural period of the target. (Reference 14) In the experiments at Picatinny Arsenal, Southwest Research Corporation (Reference 8), and Suffield Experimental Station (Reference 9), it was been found that the reflected pressure on a cylindrical model, of approximately the size of the targets used in the Picatinny Arsenal tests, is 2.5 to 3 times as great as the overpressure. The

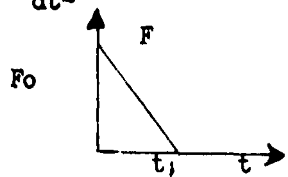
experiments at all three installations were carried out at approximately 25 psi overpressure. In the computation of "dynamic load factors", a factor of 2.5 was used as the ratio of face-on reflected pressure of the cylindrical shell to the free air overpressure for targets 1 and 4. Curves such as figures 3 and 4 of BRL Report No. 988 (Reference 4) indicate that in the higher impulse and pressure regions a factor of from 4 to 8 for the ratio of face-on pressure (impulse) to side-on pressure (impulse) is more likely. It can be shown (Reference 10) that a maximum factor of 8 can exist for strong shock waves as a ratio of face-on pressure to side-on pressure. Therefore it seems reasonable to use a factor greater than 2.5 for target No. 2, so that better correlation exists between the two techniques shown in Table 3 (e.g. for a factor of 4.5 the predicted buckling pressure is approximately 100 psi for target #2). Likewise at low pressures and impulses, a reflected pressure factor of 2.5 is too great for the ratio of face-on to side-on pressure (e.g. for a factor of 2.0 for target #3 the predicted buckling pressure is approximately 13 psi). As further experiments are carried out at Picatinny Arsenal, Ballistic Research Labs and Suffield Experimental Station, the pressure distribution around a circular shell for various shell geometries and shock strengths will be determined. These corrections will then be incorporated into future theoretical analyses.

APPENDIX I

Determination of Dynamic Load Factor Based on Triangular Type of Impulse Loading (Reference 7)

The differential equation for the triangular impulse loading for a simple one degree of freedom system is,

$$m\frac{d^2x}{dt^2} + kx = Fo - Fo\left(\frac{t}{t_1}\right)$$



Larson then solves this differential equation, noting that

$$w^2 = \frac{k}{m} \quad \text{where} \quad w = \sqrt{\frac{gp}{yc}}$$

The solution is

$$x = \frac{Fo}{kwt_1}\left[\sin(wt) - wt_1 \cos(wt) - w(t-t_1)\right] \quad c \leq t \leq t_1$$

$$x = \frac{Fo}{kwt_1}\left[\sin(wt) - wt_1 \cos(wt) - \sin w(t-t_1)\right] \quad t \geq t_1$$

where F = concentrated load (lbs);

F_o = peak concentrated load (lbs)

t = time (sec)

t_1 = duration of pulse (sec)

k = spring constant (lbs/in.)

m = mass (lbs-sec^2/in.)

x = amplitude of deflection (in)

g = acceleration due to gravity (in/sec^2)

y = maximum static deflection of structural element (in)

p = load (lbs/in)

c = weight of structural element per unit length (lbs/in)

and A = Dynamic load factor

W = Weight of explosive (lbs)

Z = Scaled distance (feet/lbs $^{1/3}$)

used on p. 15

The general equation for a spring force S for $t \leq t_1$ is:

$$S = kx = F_o \left[1 - \frac{t}{t_1} - \cos wt + \frac{\sin wt}{wt_1}\right]$$

The ratio of the spring force S to the maximum dynamic load F_o will be defined as the dynamic load factor and noted as A (Reference 14). If a target buckles statically at P_b, then under dynamic conditions which lead to dynamic load factor A, the target will buckle at P_b/A. The maximum dynamic load factor when the peak amplitude occurs for $o < t < t_1$ is:

$$A = 1 - \frac{wt}{wt_1} - \cos wt + \frac{\sin wt}{wt_1}$$

A sample computation of the dynamic load factor for target No. 1, in a test using 10,000 lbs. of TNT placed on the ground in an hemisphere so as to obtain a reflection factor of 1.8, follows.

The static buckling pressure computed for the cylindrical portion of target No. 1 is computed from the relation, (Reference 12).

$$P_b = \frac{.865\ E}{\frac{L}{R}\left(\frac{R}{h}\right)^{2.5}}$$ For a material with a Poisson's Ratio = 0.3

where;

P_b = critical buckling pressure, (psi)

E = youngs modulus, (psi)

h = shell thickness, (in.)

L = unsupported length of cylinder, (in.)

R = radius of cylinder, (in.)

For Target No. 1 P_b = 150 psi

Using a factor of 2.5 for the ratio of face-on reflected pressure of the cylinder to the free-air overpressure, an overpressure of

$$\Delta P = \frac{150}{2.5} = 60 \text{ psig is used in the analysis.}$$

The scaled distance from the center of charge (10,000 lbs) where 60 psi overpressure will be experienced is

$$Z = 3.9 \frac{ft}{lbs^{1/3}} \qquad \text{(Reference 4, 5, 6)}$$

$$Z = \frac{\text{Distance from charge (R)}}{\text{(Explosive Weight)} \quad \text{(lbs)}^{1/3}}$$

$$R = (10{,}000 \times 1.8)^{1/3} (3.9) = 102.5 \text{ feet.}$$

For a scaled distance of 3.9 (Reference 4)

$$\frac{t_1}{W^{1/3}} = .7$$

or the length of the pulse, t_1 = 18.4 msec.

The maximum static load deflection from Roark, (Reference 12), Table XIII, Case 12 is

$$y = (.0136)\ (10^{-6})\ R^{3/4}\ L^{3/2}\ h^{9/4}\ p$$

The weight of the aluminum target is

$$c = (.100)\,\pi\, D\, h = .628\ Rh$$

Then,

$$wt_1 = \left(\sqrt{\frac{gp}{yc}}\right) t_1 = \left[\frac{386 \times 10^6 \times h^{9/4}}{.0136 \times R^{3/4}\ L^{3/2} \times .628\ Rh}\right]^{1/2}$$

$$wt_1 = 2.13 \times 10^5\ \frac{h^{5/8}\ t_1}{R^{7/8}\ L^{3/4}}$$

For target No. 1

$$wt_1 = 47.8$$

The number of radians to the point of maximum amplitude is:

$$wt_1 \sin wt + \cos wt = 1$$

$$wt = 3.125$$

The maximum dynamic load factor:

$$A = 1 - \frac{wt}{wt_1} - \cos wt + \frac{\sin wt}{wt_1}$$

$$A = 1.934$$

Therefore under the conditions cited (i.e. 102.5 feet from 10,000 lbs of TNT w/Reflection factor = 1.8) the target should buckle at an overpressure of

$$\Delta P = \frac{60}{1.934} = 31 \text{ psig.}$$

REFERENCES

1. W. G. Marple, "Progress Report No. 1, W. E. B. Program" Picatinny Arsenal Technical Memorandum No. 114-62.

2. S. Glasstone, "The Effects of Nuclear Weapons", United States Atomic Energy Commission, April 1962.

3. W. Flugge, "Stresses in Shells", Springer-Verlag, 1960.

4. A. J. Hoffman, S. N. Mills, Jr. "Air Blast Measurements About Explosive Charges at Side-on Normal Incidence", Ballistic Research Laboratories Report No. 988.

5. H. J. Goodman, "Compiled Free-Air Blast Data on Bare Spherical Pentolite", Ballistic Research Laboratories Report No. 1092.

6. J. Moulton, Jr., "Nuclear Weapons Blast Phenomena" (U) Vol. 1 Defense Atomic Support Agency, DASA 1200, March 1960, Secret.

7. C. Larson, "Calculation of Triangular Type of Impulse Loadings", Picatinny Arsenal Report No. 61-EA-28.

8. Southwest Research Corporation, Department of Structural Research, "Theoretical Study on the Response of Structures to Induced G-Loads", Progress Letter No. 10, January 1962.

9. Suffield Experimental Station, "Scientific Observations on the Explosion of a 20 Ton TNT Charge", Volumes 1 and 2, Report No. 203, September 1961.

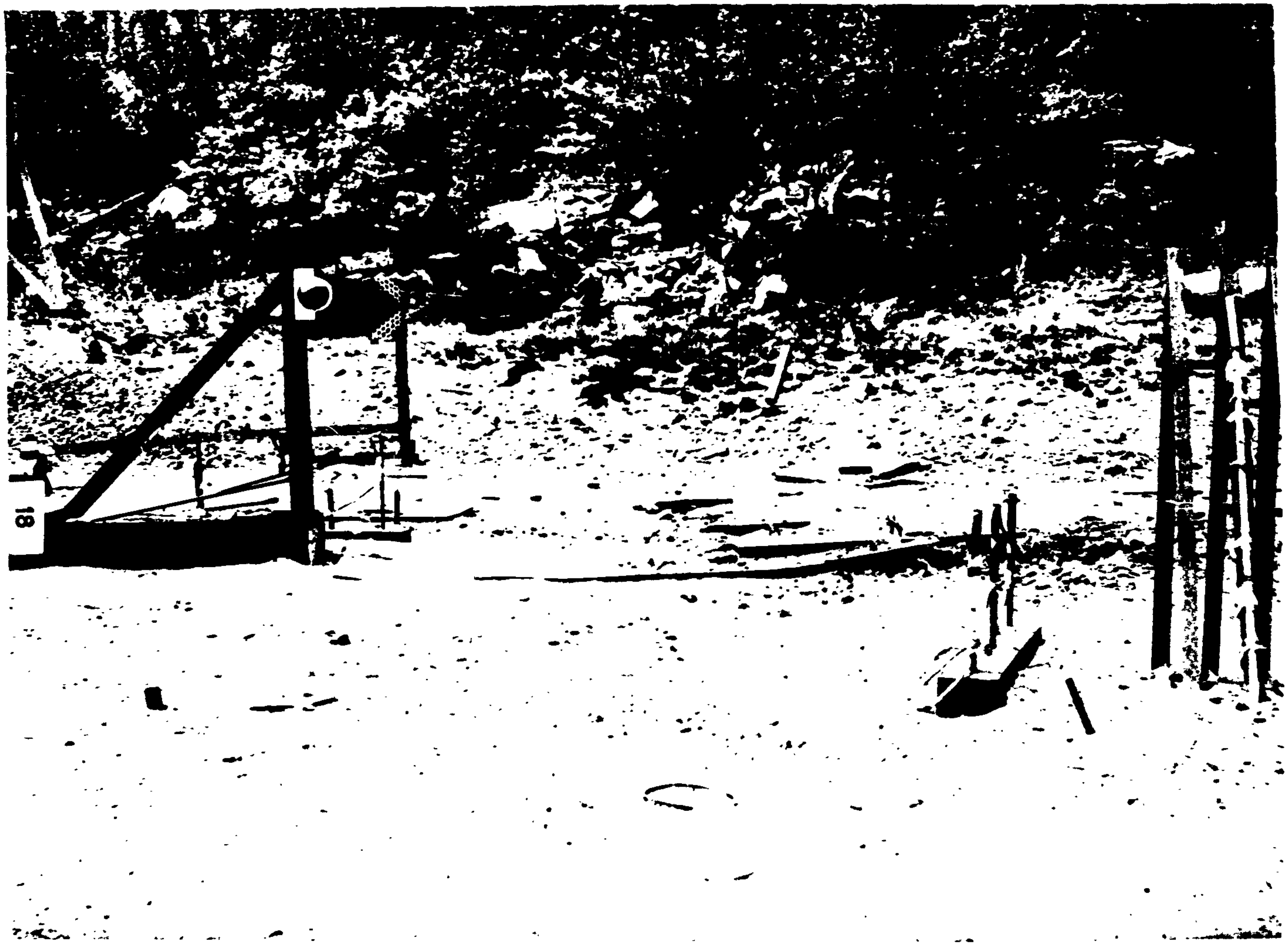
10. Courant and Friedrichs, "Supersonic Flow and Shock Waves", Vol. 1, Intersciences Publishers, Inc., New York, 1948.

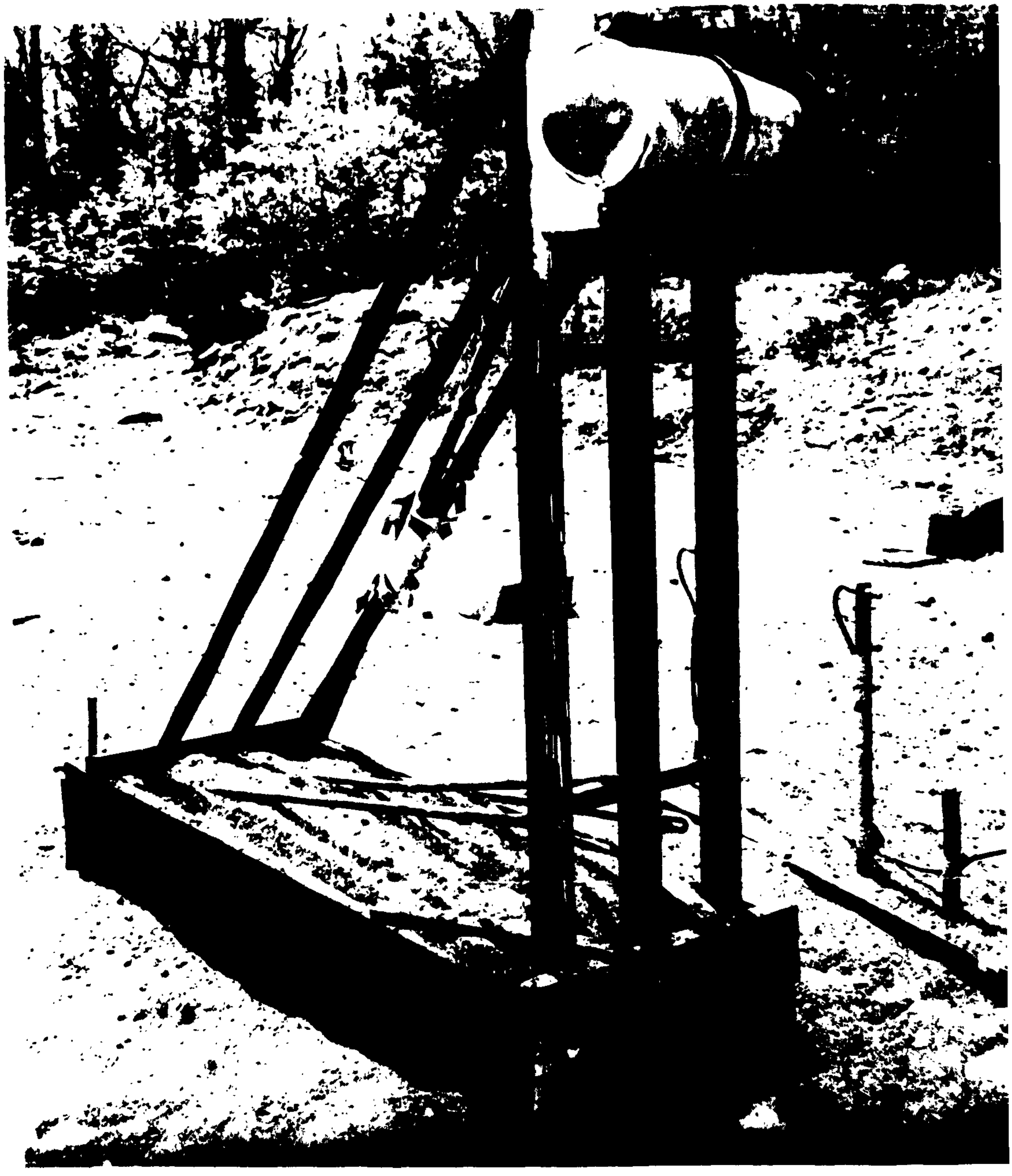
11. Unpublished Data of W. Schuman, Special Projects Branch, Ballistic Research Laboratories.

12. R. J. Roark, "Formulas for Stress and Strain", McGraw-Hill Book Company, Inc., 1954.

13. P. K. Stein, "Measurement Engineering" Volumes 1 and 2 Stein Engineering Services, Inc., 1962.

14. J. M. Frankland, "Effects of Impact on Simple Elastic Structures", Proc. Soc. Exp. Stress Analysis, Vol. VI No. 2, 1948, pp. 7-27.

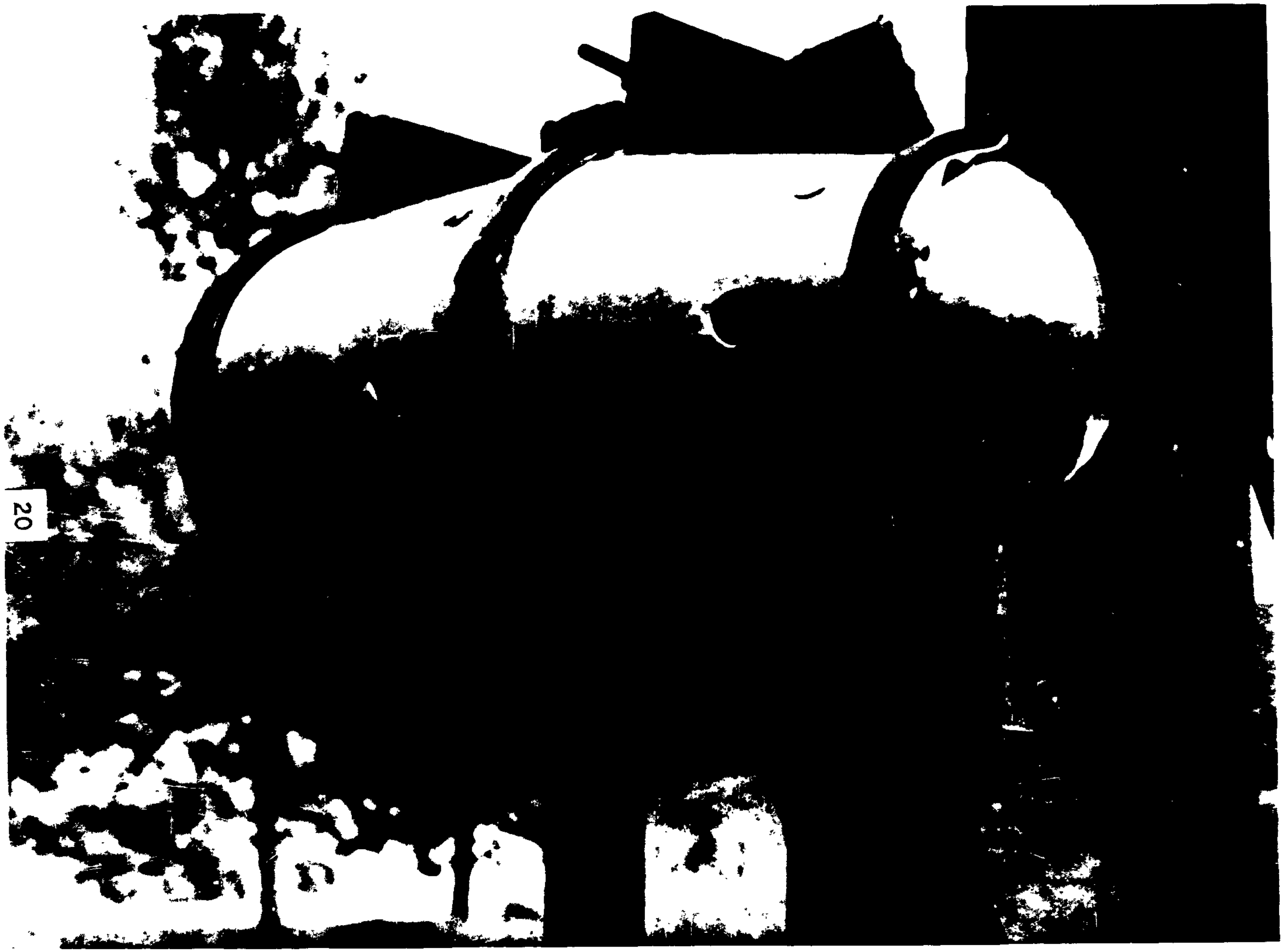

18

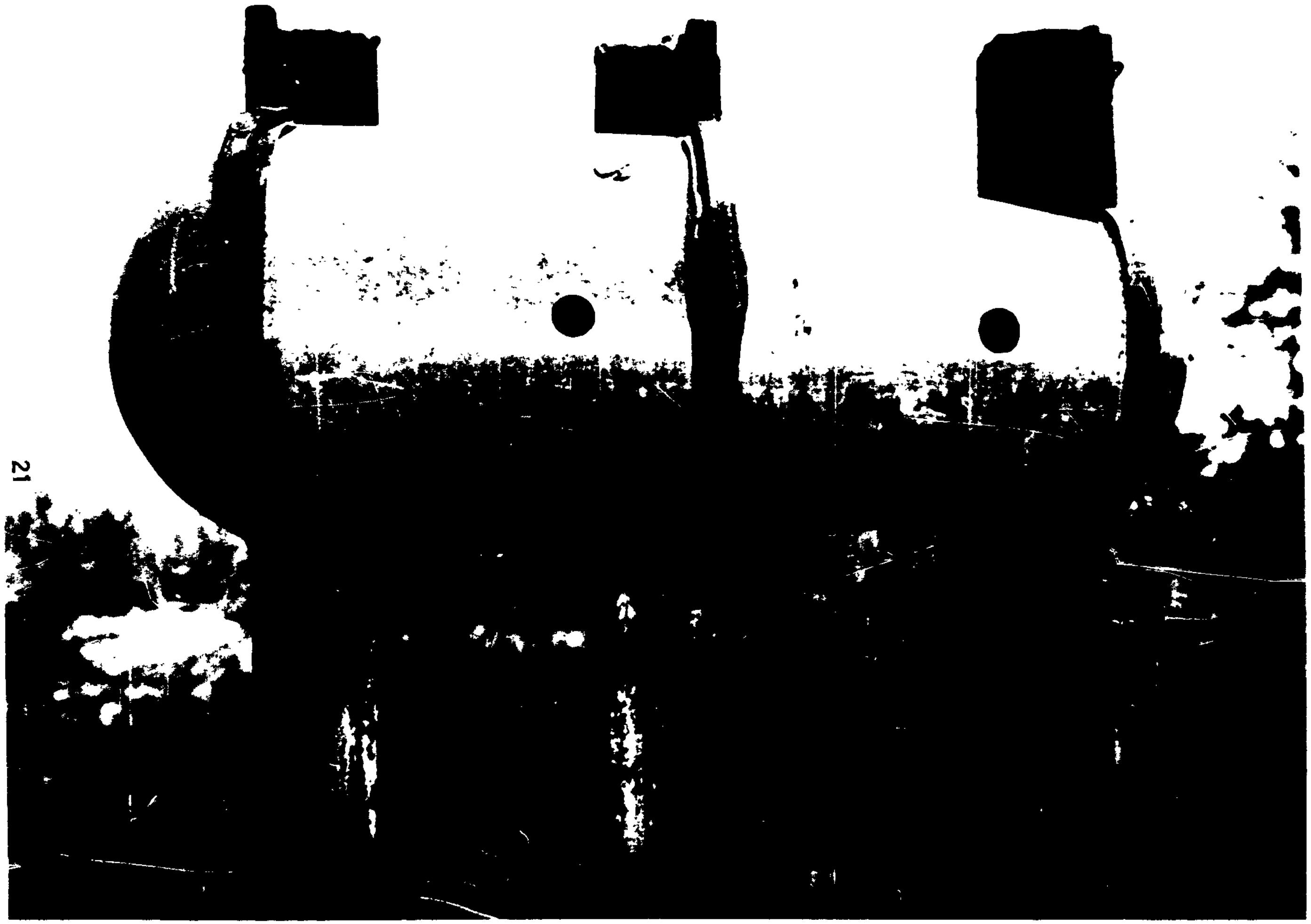


28-017-656/Ord-62	PICATINNY ARSENAL	ORDNANCE CORPS

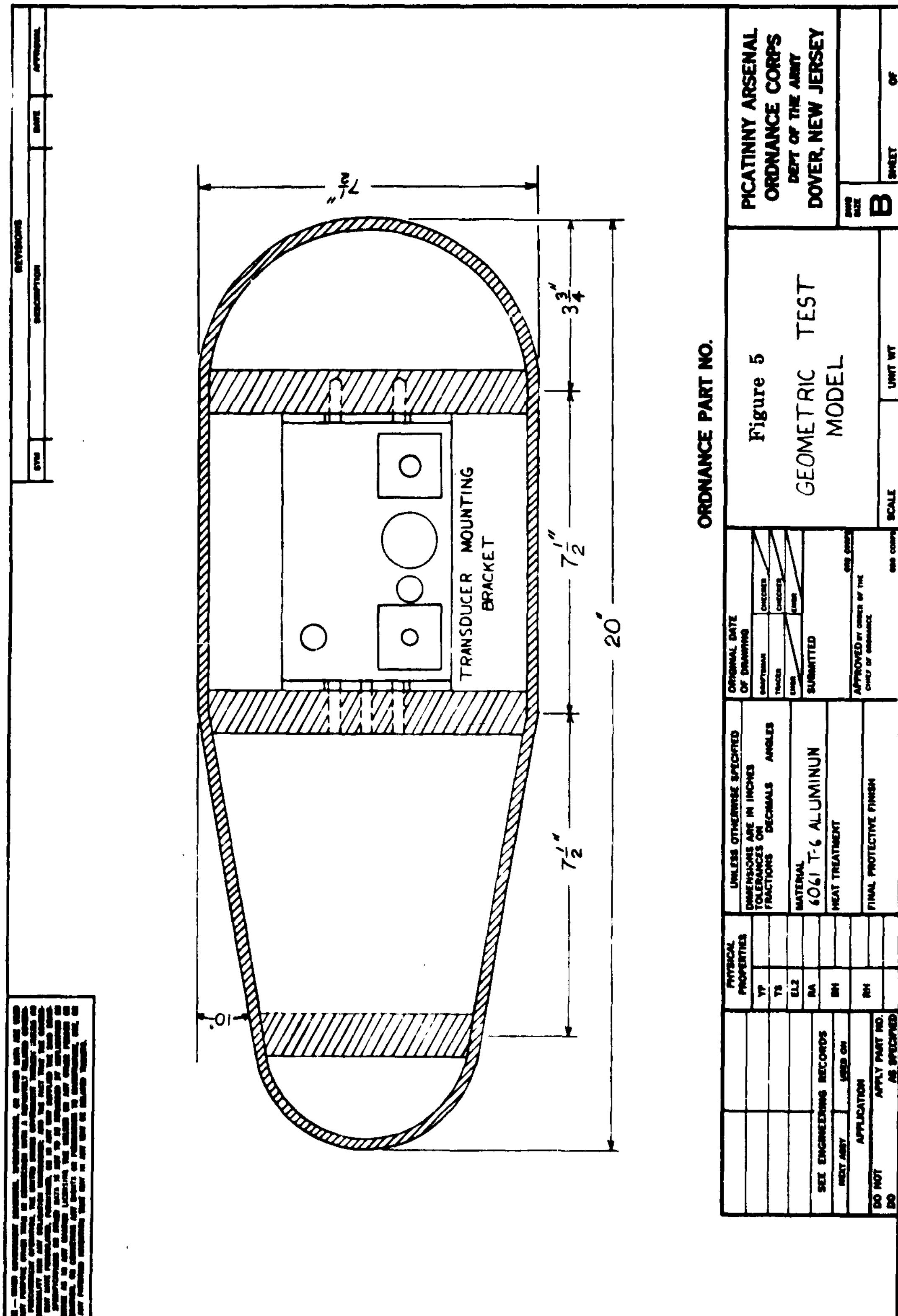
Figure 2

Steel Stand W/Wooden Sand-Filled-Box-Base

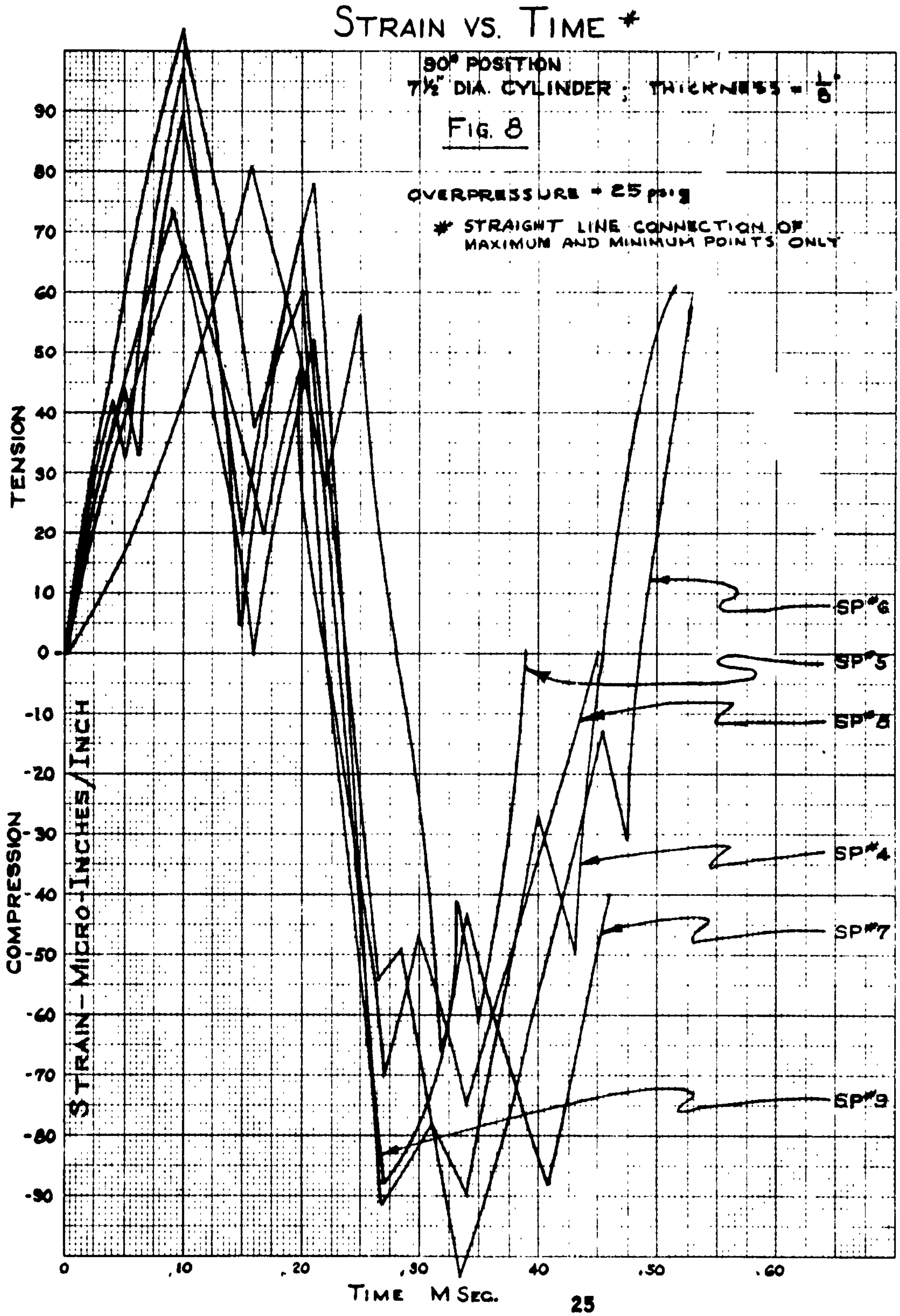

20



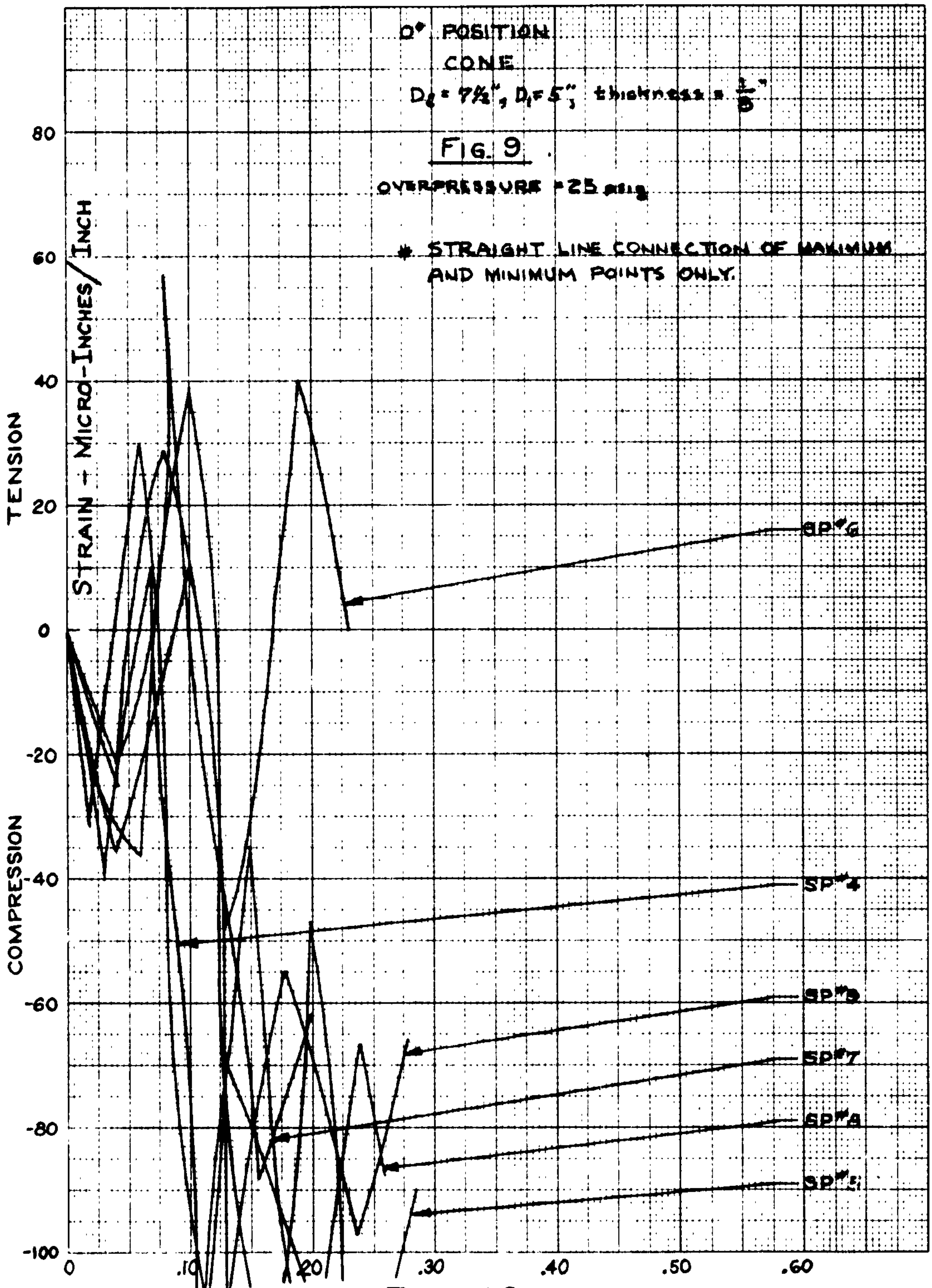
21

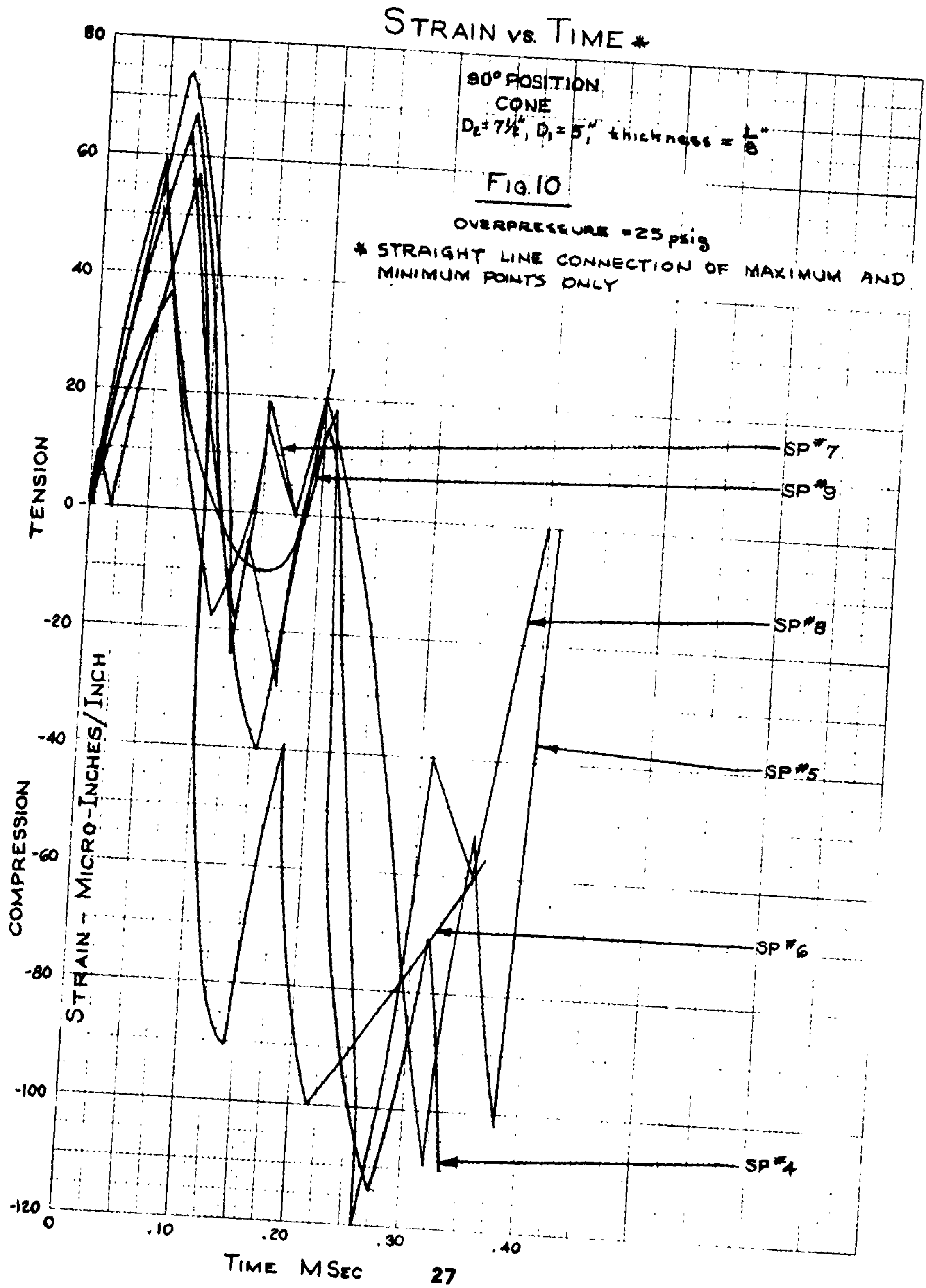

PICATINNY ARSENAL
ORDNANCE CORPS
DEPT OF THE ARMY
DOVER, NEW JERSEY
ORDNANCE PART NO.
Figure 5
GEOMETRIC TEST MODEL
TRANSDUCER MOUNTING BRACKET
6061 T-6 ALUMINUN
20″
7½″
7½″
3¾″
7¼″
.10
REVISIONS
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
MATERIAL
HEAT TREATMENT
FINAL PROTECTIVE FINISH
SUBMITTED
APPROVED
SCALE
UNIT WT
SHEET
OF
B

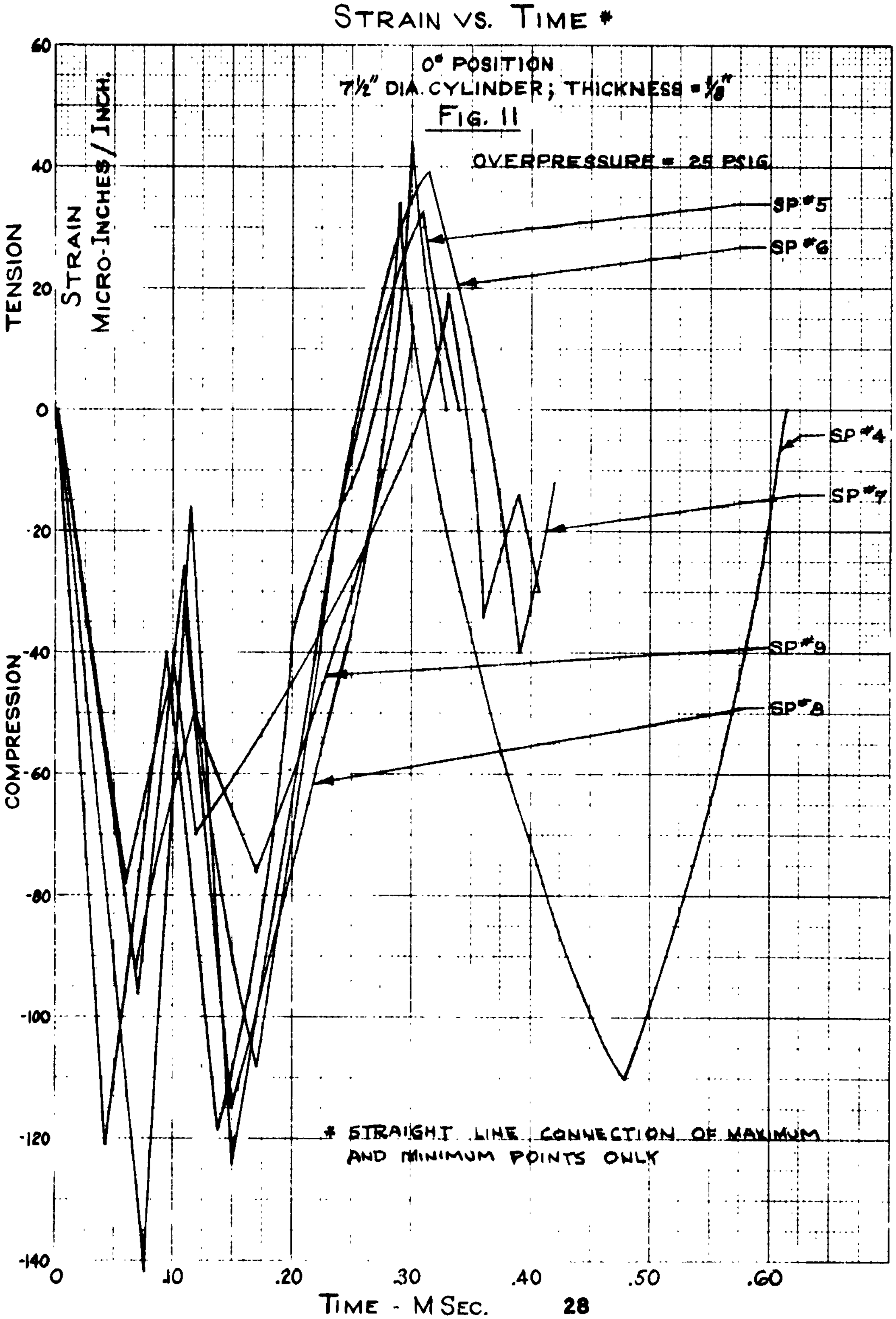

23

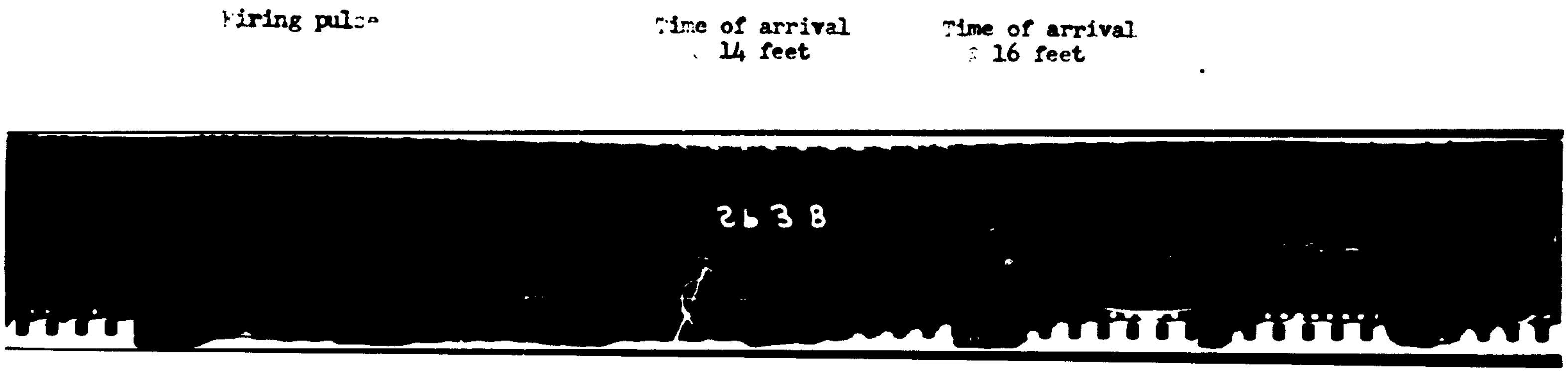

STRAIN VS. TIME *
90° POSITION
7½" DIA. CYLINDER ; THICKNESS = 1/8"
FIG. 8
OVERPRESSURE = 25 psig
* STRAIGHT LINE CONNECTION OF MAXIMUM AND MINIMUM POINTS ONLY
SP#6
SP#5
SP#8
SP#4
SP#7
SP#9
TENSION
COMPRESSION
STRAIN-MICRO-INCHES/INCH
TIME M SEC.

STRAIN VS. TIME *




STRAIN vs. TIME *
90° POSITION
CONE
$D_2 = 7\frac{1}{2}"$, $D_1 = 5"$, thickness = $\frac{1}{8}"$
FIG. 10
OVERPRESSURE = 25 psig
* STRAIGHT LINE CONNECTION OF MAXIMUM AND MINIMUM POINTS ONLY
SP #7
SP #9
SP #8
SP #5
SP #6
SP #4
80
60
40
20
0
-20
-40
-60
-80
-100
-120
TENSION
COMPRESSION
STRAIN - MICRO-INCHES/INCH
0
.10
.20
.30
.40
TIME MSec


STRAIN VS. TIME *
0° POSITION
7½" DIA. CYLINDER; THICKNESS = ⅛"
FIG. 11
OVERPRESSURE = 25 PSIG
TENSION
COMPRESSION
STRAIN MICRO-INCHES/INCH.
SP #5
SP #6
SP #4
SP #7
SP #9
SP #8
* STRAIGHT LINE CONNECTION OF MAXIMUM AND MINIMUM POINTS ONLY
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
0
.10
.20
.30
.40
.50
.60
TIME - M SEC.



[illegible]-3, Target [illegible] 2

Time of arrival, 2 foot interval

Pressure, 0 degrees, cylinder

Pressure, 45 degrees, cylinder

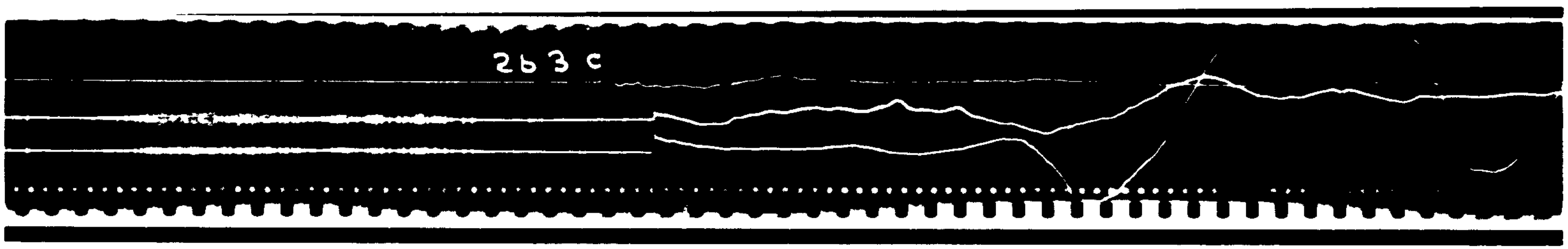
Timing, 10 [illegible]

Figure 12

Firing pulse

Time of arrival
@ 14 feet

Time of arrival
@ 16 feet



TEST OF 3,   Target No. 2

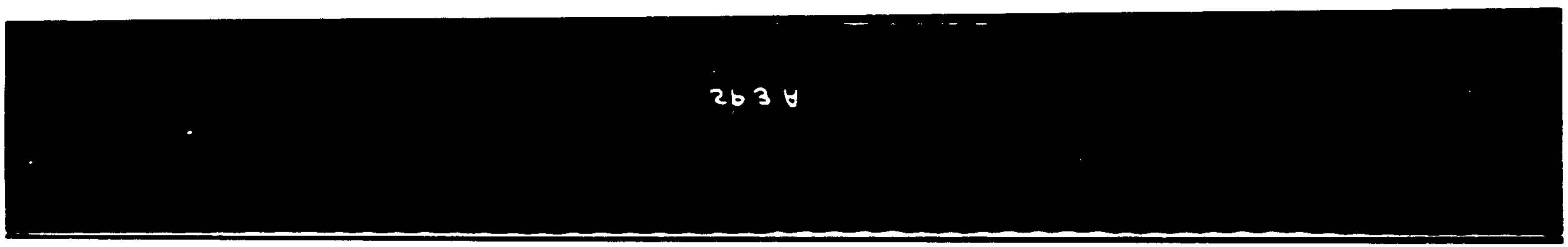
Time of arrival, 2 foot interval

Pressure, 45 degrees, cone

Pressure, 0 degrees, cone

Timing, 10 KC

Figure 13



3, Target No. 2

train, 90 degrees, cylinder

train, 90 degrees, cone

train, 0 degrees, cone

train, 0 degrees, cylinder

Timing, 10

Figure 14

DISTRIBUTION LIST

	Copy No.
Commander Aeronautical Systems Division ATTN: Captain S. Garner Air Force Systems Command Wright Patterson Air Force Base, Ohio	1, 2
Commanding General U. S. Army Materiel Command ATTN: AMCRD-DE-N, Maj. Kurtz Mr. R. Thorkildsen Washington 25, D. C.	3
Commanding General U. S. Army Munitions Command	
ATTN: AMSMU-D, Mr. G. Chesnov	4
AMSMU-W-A	5, 6
Dover, New Jersey	
Commanding Officer U. S. Army Ballistic Research Laboratories	
ATTN: Dr. E. Minor	7
Mr. J. Meszaros	8
Mr. A. Hoffman	9
Aberdeen, Maryland	
Armed Services Technical Information Agency Arlington Hall Station Arlington 12, Virginia	10-27
Commanding Officer Picatinny Arsenal	
ATTN: Director, Feltman Research Laboratories	28
Chief, Engineering Sciences Laboratory	29
Technical Assistant for Nuclear Effects	30
Technical Assistant for Physics	31
Chief, Advanced Concepts Section	32
Chief, Advanced Systems Unit	33
Mr. Lawrence Rosendorf	34-49
Chief, Nuclear Warheads & Effects Unit	50
Chief, Engineering Research Section	51
Director, Nuclear Weapons Group	52
Chief, Nuclear Weapons Development Division	53
Chief, Long Range Atomic Warheads Laboratory	54
Chief, Atomic Ammunition Development Laboratory	55
Chief, Nuclear Systems Section	56